Educator Resource: Students' Learning Progressions for the *Plants* Unit

The *Carbon TIME* curriculum is based on learning progression research. Learning progressions are descriptions of the informal and then successively more sophisticated (scientific) ways that students reason about phenomena. *Carbon TIME* researchers have investigated how students understand and learn to make sense of carbon-transforming processes. You will find many of our publications and presentations under the Research Tab on the *Carbon TIME* website. (See, for example, Learning Progressions and Climate Change, by Joyce Parker, et al.)

Here, we offer a brief overview of the specific learning challenges that your students are likely to face as they study the *Plants* Unit. We focus on students' practices associated with their roles as questioners, investigators, and explainers.

Students as Questioners

Some students are curious about plants and have lots of questions, other students less so. But even curious students must learn how to ask productive questions about tracing matter and energy. Students' questions play an essential role as they work on the Expressing Ideas and Questions Tool and the Evidence-based Arguments Tool.

The Expressing Ideas and Questions Tool asks students for their questions, and consensus questions are an important outcome for this discourse routine. These questions will drive later activities and discussions. Here are some facts about plants that many of your students are likely to know before they start the unit:

- Plants need light, water, air, and soil nutrients to grow.
- "Plants make their own food" (and some students will be familiar with the word "photosynthesis.")
- Plants breathe in CO_2 and breathe out O_2, the opposite of animals.
- Food chains and food webs start with plants.

So some students are likely to feel that "they already know a lot about plants," seeing little need to ask additional questions. Students may have "wondering questions" about how we can get plants to grow better or why plants are green.

The wondering questions are important, but students also need to recognize that the facts they know fall short of the *Carbon TIME* (and NGSS) goal of tracing matter and energy through growing plants. So comparing the facts above with *Carbon TIME*'s Three Question and with principles of matter and energy conservation suggests some important questions:

- What happens to light, water, air, and soil nutrients when plants grow? How are they changed into the materials that plants are made of?
- If "plants make their own food" and soil nutrients are also "plant food," what's the difference between those two kinds of "food?"
- What happens to the carbon in the CO_2 that plants breathe in?

Other productive questions for the unit ask about *mechanisms* (e.g., What's happening inside the radish plant as it grows?) and about *tracing matter and energy* (e.g., How are materials moved around and changed when a tree grows?).

Later in the unit, students completing the Evidence-based Arguments Tool generally need help identifying questions that result from limitations in their investigations and results. For example, the investigation provides evidence about matter and energy that go into or come out of the radish plants (macroscopic scale), but not about how they are being changed inside

the radish plants (atomic-molecular scale). Encouraging as-yet unanswered questions about how matter and energy change inside the radish plants prepares students to answer those questions through the subsequent molecular modeling activities.

Students as Investigators

Students are naturally inclined to pursue "engineering investigations" about how different conditions and nutrients affect plant growth, but not "matter-tracing investigations" about how matter and energy are moving through and transformed in plant systems. In fact, it will be hard for many students to see how their investigations can answer questions about mechanisms or tracing matter and energy. It is especially important for students to figure out how their tools—the digital balances, BTB, and their senses—can be used to trace movements and changes in matter and energy.

- The digital balance is a *matter movement detection tool:* The rules on the Three Questions say that matter (solids, liquids, or gases) MUST be moving out of a system that loses mass and MUST be moving into a system that gains mass. Most students are pretty good at applying this reasoning to solids and liquids: They notice that the growing plants absorb water and gain mass. But they struggle to interpret evidence about movement of gases: If the plant-soil system gains dry mass, then gases MUST be adding mass to the system. So it is important for students to notice that growing plants gain more dry mass than the growing medium loses, and to consider how that result is evidence for matter movement.
- BTB is a *matter change detection tool:* The light-dark investigations provide evidence for two different chemical changes:
    - The amount of CO_2 in the air goes up when plants are in the dark, so there must be a chemical change that is producing CO_2.
    - The amount of CO_2 in the air goes down when plants are in the light, so there must be a chemical change that is using CO_2.
- The students' senses are *energy change detection tools:* Student can see the plants growing; this can lead to questions about whether there is chemical energy in the plants, and where it might have come from. They can also see that the plants need light to go; this can lead to questions about how the light energy is transformed inside the plants.

When students are using the Predictions and Planning Tool to plan their investigations, they may need help to see how they can use the digital balance, BTB, and their senses to provide evidence that addresses the Three Questions about matter movement, matter change, and energy. And when they are using the Evidence-based Arguments Tool, they may need help to see how their evidence provides them with partial, but not complete, answers to the Three Questions.

Students as Explainers

Our learning progression research shows three levels as students become more scientifically sophisticated in their explanations:

- *Force-dynamic explanations* (Learning Progression Level 2) describe plants as "actors" that have needs—light, water, air, and soil nutrients—to accomplish their purposes, especially growing. In the Big Idea Probe about what happens to a house plant in a sealed container, Mom ("The plants will keep growing forever because plants have everything they need. They can make their own food as long as they have light.") and Grandma ("The plants will die because they will use up all the water in the container.") express Level 2 ideas.

- *Incomplete matter-tracing explanations* (Learning Progression Level 3) recognize that matter and energy are moved and changed when plants grow. They may try to trace matter and energy, but without following all the rules of the Three Questions. On the Big Ideas Tool Marco suggests a Level 3 prediction ("The plants will die because they require carbon dioxide and they will use up all the carbon dioxide in the container.").

  Level 3 explanations commonly focus on solids and liquids, but not gases. So they recognize that water and soil nutrients are absorbed by plant roots and contribute to the mass of the growing plant, and that plants "breathe in" CO_2, but they find it hard to believe that CO_2 is the main source of plants' dry mass. Level 3 explanations also commonly do not clearly distinguist between matter and energy, saying, for example, that "photosynthesis is how plants convert sunlight into food."
- *Complete matter and energy-tracing explanations* (Learning Progression Level 4) answer the Three Questions while following the rules. On the Big Ideas Probe, students who understand Level 4 explanations will agree ONLY with Carla ("The plants will stop growing but will still live because their growth is limited by how much carbon is in the container.").

The activities and tools in Lessons 4, 5, and 6, including the molecular modeling activities, the Explanations Tools, and the readings and worksheets in Lesson 6, are all designed to scaffold the students' explanations as they make the difficult progression from Level 2 to Level 4 explanations.